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Computer-assisted learning and evaluation in medicine.

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AUTHOR ABSTRACT: ABSTRACT: The use of the computer in **medical** education has been in evolutionary development since the early 1960s; its adoption, however, has been less widespread than the promise of the medium should warrant. Computer-assisted instruction enhances learning, allowing the student the discretion of content, time, place, and pace of instruction. Information conveyed can take several forms, some better suited to undergraduate **medical** education, others more applicable to graduate and continuing education. The use of the computer in certification and licensure could, within a decade, transform the way competence is assessed. Its greatest promise, however, may lie in providing pertinent information at the time when, and in the place where, **patient** care takes place. New developments in data storage and retrieval forecast applications that could not have been imagined even a year or two ago.

TEXT:

If automobiles had pursued the same technological path that computers have, Americans would now own half-pound cars, costing less than $4.50, and getting 1.5 million miles to the gallon.

Michael Blumenthal

WITH increasing, fervor, leaders in **medical** education are recognizing the need for change in both the substance and style of **medical** education. [n1,n2] The reasons for this are clear:

* Between 6000 and 7000 scientific articles are published in the world each day.
* Scientific information is increasing at the rate of 13% each year.
* The scientific database is doubling every 5.5 years -- and in some domains even faster. [n3]

It is simply not possible to infuse all of biomedical knowledge into the student -- whether at the undergraduate, graduate, or the postgraduate level. Indeed, many fear that the attempt continues to be made at the expense of the process of cogent **patient** care. Even as problem solving and decision analysis assume greater importance because of new technology, they are being sacrificed for rote memorization of proliferating facts. The Panel on the General Professional Education of the Physician of the Association of American **Medical** Colleges (AAMC) in its report in 1984 [n2] made critical recommendations for change:

* **Medical** faculties must limit the amount of factual information that students are expected to memorize.
* **Medical** faculties should adopt methods to identify students who have the ability to learn independently and provide opportunities for their further development of this skill.
* **Medical** faculties should consider major reductions in passive learning and require students to be active, independent learners and problem solvers.
* **Medical** schools should lead in the application of information science and computer technology and promote their effective use.

Only the latter of these excerpted recommendations is new. The others were enunciated by the AAMC in a report on the status of **medical** education as long ago as 1932. [n4] But it is the latter that provides the greatest opportunity for change as we prepare to enter the 21st century. Computer technology has the power and capacity to facilitate independent learning and to teach problem solving in a manner unmatched by any other medium.

Three decades ago television was heralded as the medium with the capacity to transform education. The very best educators in all disciplines could be made available inexpensively to students around the country. The promise never materialized. First of all, proponents underestimated the chauvinism of faculty. More important, however, television is fundamentally a passive medium. Indeed, it proves to be more passive than the lecture --

learners have no opportunity to interact with teachers. By contrast, the computer is intrinsically interactive, constantly engaging the learner even in its simplest mode of operation ("drill and practice"). Barnett and colleagues [n5] point out that in contradistinction to all other modes of education, "We can at least be sure that our users are awake."

To understand both the power and the limitations of the application of the computer in **medical** education, it is useful to review its development during the past 25 years.

DEVELOPMENT OF COMPUTER-ASSISTED INSTRUCTION IN **MEDICAL** EDUCATION

The earliest efforts to apply to computer in **medical** education were begun in 1961. [n6] The process of entering data through punched cards (batch processing) and the limitations of relatively primitive (by today's standards) computer languages, however, inhibited any widespread application. As batch processing gave way to interactive keyboard entry of data in the late 1960s, major developments in computer-assisted instruction occurred in quick succession at several American **medical** colleges. (While the terms "computer-based learning," "computer-assisted education," and others have been used, the differences are largely semantic. "Computer-assisted instruction" [CAI] is widely understood and will from the most part be used here.)

One of the first of these schools was Ohio State University. [n7,n9] There CAI began in 1967 as a one-terminal, one-course system. In 1969 the program, by then called "TES" (Tutorial Evaluation System), was incorporated into the evolving Independent Study Program in the basic **medical** sciences. Production of lessons was greatly assisted by the development of COURSEWRITER III, a computer program that allows an instructor to enter text in response to computer guidance without any need for knowledge of programming. By the middle 1970s Ohio State had a library of more than 350 interactive hours, adding five hours per month. The format of the Independent Study Program, reinforced by the presence of the computer, established a relatively new concept in **medical** education: mastery of content of subject matter was the constant; time in the curriculum, the variable.

At about the same time, the Massachusetts General Hospital Laboratory of Computer Science under the direction of G. Octo Barnett [n10,n11] began developing simulations of **clinical** encounters. Employing a computer language developed for the purpose [n12] and a well-designed instructional strategy, these simulations became highly sophisticated. By the middle of the 1970s, the laboratory had developed more than 30 simulations with multiple cases within each simulation.

A third contemporary development occurred at the University of Illinois, where Harless et al [n13] developed a somewhat different type of **simulation** model that they termed "CASE" (**Computer** -Associated **Simulation** of the **Clinical** Encounter). These simulations became sufficiently well developed that the American Board of Internal Medicine gave serious consideration to the use of them in a **program** for recertification that was to be called "MERIT" (Model for Evaluation and Recertification Through **Individual** Testing). [n14]

A common feature of the three systems described was that they ran on mainframe computers, accessible over telephone lines, with the capacity to time-share. Stimulated in part by a landmark challenge by Stead et al, [n15] the Lister Hill Center of the National Library of Medicine in 1972 undertook the sponsorship of a consortium to share these educational resources, paying the costs of access via a national computer network. [n16] The Massachusetts General Hospital, Ohio State University, and the University of Illinois served as hosts. More than 150 institutions participated in the program. Thousands of hours were logged by students around the country.

Meanwhile, development of CAI burgeoned around the country. [n17-22] Two of these developments deserve special mention. One is the simulation model developed by Friedman [n23] at the University of Wisconsin, notable in that it became the prototype for what is now being implemented as the Computer-Based Examination by the National Board of **Medical** Examiners. The second is a program called "GUIDON," developed by Clancey and colleagues [n24] at Stanford. Using principles derived from the field of artificial intelligence, they developed tutorial rules that interacted with the diagnostic rules of a **medical** expert system known as "MYCIN," [n25] a program advising physicians about the proper choice of an antibiotic. That work subsequently led to a reimplementation of MYCIN (known as "NEOMYCIN")

and has evolved into a more advanced version, GUIDON-2. [n26]

Despite all this promising activity, interest and new developments began to decline in the middle to late 1970s. Some observers became cynical: "Never before have so many accepted the unrefined technical fantasies of so few. Never before has so much been spent for what has been so little understood or thought out." [n27] (That same observer, it should be noted, termed "videorecords" a fiction and called artificial intelligence and information retrieval "brittle concepts." He went on to say that the "nearest computer cannot possibly hold everything you want to read." What a difference ten years can make])

It is true, however, that in the mid-1970s there were major obstacles to the further evolution of computer-based learning.

IMPEDIMENTS TO THE DEVELOPMENT OF CAI

Limitations on Transferability

Perhaps the most damaging barrier to widespread dissemination of CAI a decade ago was the inability of programs written for one system to be readily run on another machine. A system called "PLATO," for example has been heavily used at the University of Illinois, Champaign-Urbana. (Through 1981, students and faculty clocked 9 000 000 hours of use; there were 12 000 hours of instruction available in 150 subject areas. [n28]) It, however, is a stand-alone system. Hardware is marketed by Control Data Corporation and must be purchased "as is." The language used (TUTOR) will run only on PLATO hardware.

COURSEWRITER III, used to develop CAI at Ohio State, was supported only on the IBM 360 and 370 and must be substantially (and expensively) modified to run on other hardware. PILOT, a very useful authoring language, has repeatedly had to be rewritten for use on different machines. A survey of the status of **medical** CAI in 1974 identified 362 programs in 23 different computer languages. [n29]

Even today, developers of CAI tend to embellish their programs with color, graphics, and video that require elaborate and often expensive systems, leading to the librarian's lament: Why won't this program run on something I already own?

Quite apart from limitations owing to machine incompatability, there are other impediments to transferability. [n30] One set of problems concerns documentation of programs that are designed for export. Course objectives and the instructional strategy used to develop the program by the originator do not necessarily match the objectives and the strategy of the recipient. Most programs are developed to supplement, not to substitute for instruction by other means. The developer must then provide substantial complementary material. The simulations developed at the Massachusetts General Hospital were accompanied by a 200-page manual. The user manual issued by Ohio State University ran to 150 pages and required supplementary slides. Given these constraints, instructors are sometimes motivated to design their own programs de novo. In the light of new biomedical knowledge and technology, the subject matter contained in CAI teaching programs often needs to be modified. Who is responsible for their modification -- the originator or the recipient? How is that to be accomplished?

Other problems are political in nature. There must be motivation for both the developer and the recipient to achieve successful transfer of the technology. This requires many hours of work on both sides. Unlike preparation of journal articles and books, faculty development of computer-based instructional programs is seldom considered to be relevant in decisions regarding promotion and tenure. Rarely is the developer paid for his effort. What, then is the incentive to develop and to share?

Faculty and **medical** schools are often resistant to the use of instructional materials developed elsewhere. As with the use of film and video, faculty exhibit the "NIH" syndrome (not invented here). Thus, many good instructional programs go unused.

Issues of Cost and Benefit

Until the late 1970s, computer hardware was very expensive. Even with today's microcomputers, the investment in equipment sufficient to serve adequately an entire class of **medical** students is not insubstantial-all the more so if selected programs employ sophisticated color monitors and graphic capabilities.

If an institution chooses to access computer-based instructional materials over telephone lines, there are telecommunication charges to consider. When the Lister Hill Center ceased to subsidize the programs it sponsored, the hosts were forced to charge for access. This amounted to $9

and hour to receive the Ohio State programs and $8 and hour for those from the Massachusetts General Hospital. [n16]

Should a school decide to invest in the development of its own programs, a new set of problems emerges. The faculty developer is generally only a content expert. Two other kinds of personnel are needed: educational strategists and instructional programmers. Rarely is any one person qualified at all three tasks. Content experts, strategists, and programmers must work as a team.

Development of CAI is labor intensive. In the 1970s hundreds of hours were required to develop a single hour of instruction. The group at the Massachusetts General Hospital estimated in 1978 that a year was required to develop an instructional strategy. [n31] Once that strategy was defined, an experienced author could produce a program of one hour's duration in 16 hours; an inexperienced author in 40 hours. The advent of menus and prompts in software used to develop instructional programs (so-called authoring courseware) in recent years has helped enormously. Nevertheless, experienced though they were, the staff at the Massachusetts General Hospital invested more than $ 300,000 in the development of their simulations in the 1970s.

Is development of CAI on balance cost-effective? The answer is "Maybe." Clearly, the cost per instructional hour is inversely proportional to the number of users. Cost-effective use requires a major faculty commitment to incorporate CAI in the curriculum.

CAI as a Cottage Industry

One of the major barriers to effective curricular use of CAI is a lack of information about what has been developed and is available for distribution. Countless hours have undoubtedly been spent developing programs similar to ones that might exist for the asking. Unfortunately, instructional computer programs are not cataloged in the same way books, journals, and videotapes are--even at the National Library of Medicine. Workers in CAI know a great deal about what their colleagues are doing but do not really know whether their information represents 50%, 15%, or 5% of what is available.

A universal experience is that within the walls of an institution there may be several persons independently working to create instructional materials. The AAMC General Professional Education of the Physician report accordingly recommended that **medical** schools establish academic units for the development of CAI. This would facilitate sharing and encourage the development of consortial arrangements among institutions.

Meanwhile, we muddle along. It should be noted that from time to time private efforts have been made to assemble catalogs of resources. Spedick and colleagues [n32] made such a contribution in 1975. More recently, the University of Michigan **Medical** Center published a catalog of **patient** management simulations. [n33] These efforts represent a major service.

Quality of Instructional Programs

Faculty who wish to employ computer-based instruction should understand that a great deal of what exists is of marginal quality. In the hierarchy of CAI, the simplest mode of instruction is what may be called drill and practice. While appropriate for beginning students of medicine, it rapidly loses its effectiveness and its appeal. Learners are quick to turn away from what is trivial or irrelevant.

The next rung up the ladder is the tutorial mode. This mode is again more appropriate for beginners. It is most effective if it has the capacity to bypass what the learner already knows and proceed to new material. Such programs are difficult to develop, however. Unfortunately, much of what has been developed in the tutorial mode is little more than "electronic page turning." Compared with reading books or journals, the increment in learning for the time spent at the terminal is small.

A very useful computer application is the construction of models of physiological processes such as acid-base relationships, blood clotting, and gas exchange. The learner can manipulate the variables and observe the outcome. Many useful and highly developed and are in use at **medical** schools around the country.

By far the best programs, however, have been simulations of **clinical** encounters such as those pioneered by the Massachusetts General Hospital Group. Well-designed simulations are challenging, engaging, informative, and fun. Where is it written that learning must be boring?

Perceptions of Effectiveness

Developers of CAI software are repeatedly challenged to demonstrate

that interactive computer-assisted learning is more effective than more traditional forms of instruction. The challenge leads to a circular argument: (1) There is a need to provide complete evidence of the effectiveness of CAI, but to do so requires complete and convincing demonstration. (2) To provide complete and convincing demonstration requires good programs. (3) To provide good programs requires well-trained personnel, professional awards, and a good computer system. (4) To provide well-trained personnel, professional awards, and a good computer system requires adequate funding. (5) To get adequate funding for CAI requires evidence of its effectiveness. [n21]

Effectiveness of computer-assisted learning has repeatedly been demonstrated. [n34,n35] Reductions of 33% to 67% in the time necessary to complete a course of instruction have been documented for employee training at United and American airlines, for Navy personnel taking courses in maintenance, and for students studying a variety of courses in both high school and college. [n28] Not only has well-designed CAI resulted in increments of knowledge per unit time, but it has been demonstrated to change the behavior of practicing physicians in caring for patients. Wigton and colleagues [n36,n37] have shown gains in diagnostic accuracy in the management of both urinary tract infection and sore throat following exposure to simulations.

Although a few studies have been done in **medical** education, the effectiveness of CAI is not the issue. Impediments of implementation lie elsewhere.

CAI IN **MEDICAL** EDUCATION TODAY

Much of what is developed in CAI is shared at the Annual Symposium on Computer Applications in **Medical** Care. Perusal of the proceedings for the symposia held between 1977 and 1983 reveals little that was new. The year 1984, however, saw an explosion of activity that continues to this day. Undoubtedly the reason for heightened activity is the advent of the personal computer.

The most recent curriculum directory of the AAMC [n38] shows that virtually all **medical** schools now employ the computer at least to some extent in their educational enterprise. And students demand more. A survey of graduating **medical** students two years ago revealed that students universally wished they had had more instruction by computer as well as more teaching about computer applications in medicine. No other issue received such a high rate of response (August G. Swanson, MD, oral communication, August 1987). Indeed, it is axiomatic that when computers are introduced into the curriculum, they are received enthusiastically first by the students, then by the administration, and last by the faculty.

Computer-assisted learning is used heavily at a number of **medical** schools (eg, Ohio State, Illinois). The "New Pathway" curriculum at Harvard **Medical** School includes a major emphasis on the use of information technology. Computers are readily accessible, and computer-based educational activities are integrated into the program.

Given the increasing use of CAI, certain trends can be observed.

Simulation becomes the Norm

Most of the programs developed in recent years have been in the **simulation** mode. Such programs allow learners to diagnose and manage **patient** problems, permitting errors in reasoning and judgment without penalty to anything other than their own egos. Simulations enable learners to become familiar with a spectrum of illness that they might not otherwise see. Given the current climate of low bed occupancy and brief hospital stay, the breadth of experience enjoyed by students in years **past** is becoming highly constrained. Students in clerkships today will perhaps not have the opportunity to manage common illnesses that formerly resulted in hospital admission.

Good simulations have the capacity to interrupt and prompt the learner toward preferred courses of action. Virtually all of them provide feedback either in the form of a brief tutorial or in the form of references to guide further learning.

Good simulations can be used to assess competence. Programs can be written to track and record performance. They can provide confidential **evaluation** for both the **student** and faculty. Indeed, simulations can be designed such that they are tailored to the individual to refine the **evaluation** process.

The development of the interactive videodisk has added a new dimension to simulations. The disk is capable of holding 55000 still frames

or 30 minutes of motion sequence, any element of which may be **specifically** addressed by the computer at pertinent times during an instructional session. Students maybe asked to interpret blood smears, Gram's stains, and radiographic images, or to identify characteristic physical findings. Two simulation programs developed in recent years are based on the videodisk. The first of these, the TIME project, developed by Harless and colleagues [n39] at the Lister Hill Center of the National Library of Medicine, uses voice to access segments on the disk that reveal **history** , physical findings, laboratory data, or therapeutic procedures. The second,developed by Allan, [n40] is a stand-alone system with which the learner interacts via a touchscreen. The latter is commercially available (Intelligent Images Inc, San Diego).

The Personal Computer Becomes the Standard

Standardization of hardware and software is finally well on its way to being achieved. Most of what is being developed to day is being put on floppy disk for use on personal computers. A great deal of this is becoming commercially available. A series of tutorials called "Cyberlog" is published by Cardinal Health Systems. Most of the commercial products are in the form of **patient** simulations. Most notable are the series of simulations called "Discotest" (Scientific American Inc, New York) and the simulations developed at the Massachusetts General Hospital. The latter, available for years over telephone lines and more recently via the American **Medical** Association Network (AMANET), have now been transferred onto floppy disks in a series called "RxDx" (Williams & Wilkins). All these commercial simulations are available for both the IBM-PC (or compatible) and the Apple II series.

Information and Education

To comprehend fully the role of the computer in education, one should examine two traditional information management technologies that have not customarily been classified as CAI.

The first is the matter of access to bibliographic databases. Although the National Library of Medicine's MEDLINE has been available for years, only recently has this service been exploited commercially by others for ease of access by individual students and practicing physicians using their own personal computers. An early effort was PAPERCHASE, developed at the Beth Israel Hospital in Boston. [n41] An extraordinarily use-friendly system,it quickly gained wide acceptance. It is available over the AMANET. A more recent program, developed by the National Library itself, is called "Grateful Med." It allows a bibliographic retrieval inquiry to be placed into one's personal computer. Only when the search strategy has been fully formulated does the software dial MEDLINE and submit the retrieval request. The search is executed almost instantaneously, sharply reducing communication charges.

Two recent commercial ventures have gone a step further. BRS COLLEAGUE (Saunders) and MEDIS (Mead Data Central) now make available the full text of journals and books. More than 60 journals and 30 textbooks are now available from these companies in electronic form. Such services clearly go beyond conventional bibliographic retrieval.

A second domain with educational implications is that of decision support. In the pages of this journal, Shortliffe [n42] recently reviewed the current status of computer support for **clinical** decision making. In the same issue Barnett et al [n43] described DXplain, the Massachusetts General Hospital decision-support program that has recently been made available over the AMANET. There is a fine line between education and decision support: several observers have noted that programs designed to advise the physician regarding diagnosis and management may have greater impact through education than by providing advice regarding an individual **patient** . [n44-n46]

Continuing **Medical** Education in Change

The trends and developments noted above hold the promise of profound change in continuing education. Realtime access to abstracts, and even whole articles, could change the way physicians behave. Wider availability of decision support, as the field advances, could make it as unreasonable to practice medicine without a computer as it would be to practice without a stethoscope. It would fulfill the argument articulated by Manning [n47] that education is most effective at the point at which **patient** care takes place.

THE COMPUTER IN THE EVALUATION OF COMPETENCE

For nearly 20 years the National Board of **Medical** Examiners has

been developing programs to administer its examinations by computer. That effort will soon become reality. [n48] At the heart of this effort is a simulation model known as the Computer-Based Examination (CBX). It is almost certainly the most complex simulation model yet devised. Its attributes include the following:

* The model is almost totally uncued. Candidates may order in free text any test or therapy available in a modern tertiary-care hospital.

* The **patient** "responds" to treatment in a realistic manner. Multiple pathways are built into each case, allowing alternative therapies (good or bad) to be pursued.

* Real time is simulated. Test results do not necessarily become available when ordered -- just as they would not in an actual **clinical** encounter. Meanwhile, appropriate action must be taken. A clock-advance feature allows one to move through the case.

* The computer is linked to the videodisk. Candidates must interpret blood smears, radiographic images, etc, to manage the **patient** properly.

More than 200 CBX "cases" are under development. Scoring of a candidate's performance is based on the appropriateness and timeliness of the selection of diagnostic tests and therapeutic procedures and the avoidance of tests and procedures that are unnecessary or costly or provide undue risk. Field trials in early 1987 demonstrated a high degree of reliability and an excellent capacity to discriminate optimal from less than optimal management skills.

Current plans call for the model to be available to selected **medical** schools for educational use in mid-1988. The Board is committed to its use in the licensure process as soon as a delivery system is practicable.

Perhaps the greatest importance of CBX is that it will almost certainly stimulate widespread development of CAI in general, and simulation in particular, throughout our American **medical** colleges.

THE FUTURE OF THE COMPUTER IN **MEDICAL** EDUCATION

As the computer becomes more established within the mainstream of **medical** education, **medical** faculties will find that the time commitment necessary to develop good courseware is prohibitive within a single institution. Barnett et al [n5] have argued for the creation of consortial arrangements to exchange programs. Now that some standardization of hardware environments using personal computers is being achieved, sharing may become a reality.

Meanwhile, technology and its creative use do not stand still. Several new developments portend even more change in the way we will teach and evaluate the learner.

CD-ROM

A striking new advance has been the development of the laser compact disk. [n49,n50] These disks, familiar to audiophiles around the world for their high fidelity in the recording of music, will have even greater utility in data storage. One compact disk, referred to as "CD-ROM" (compact disk-read only memory), 4.72 in in diameter, has the capacity to hold up to 550 megabytes of digitally stored information. That amount of storage is roughly equivalent to six complete sets of the Encyclopedia Brittanica. The American College of Physicians has recommended a library of 190 textbooks useful to the internist. All of these texts, taken together, would fit on one disk.

The disk readers, developed by Philips and Sony, are addressable with a personal computer. Grolier Electronic Publishing has already put the 21-volume Academic American Encyclopedia on disk. Several companies are now offering the National Library of Medicine's MEDLINE on CD-ROM.

The major problem with the technology is organizing data in such a way that it can be intelligently addressed. Philips and Sony currently have under development a keyboard that will directly address the disk drive without the intervention of a computer. The output would appear on a standard television screen. The system, known as "CD-I" (compact disk-interactive), will be available, probably within the year, at an expected price of less than $1000.

Adaptive Testing

Exciting to many in the field of testing and measurement is the concept of adaptive testing, [n51] a process that can be administered only by computer. The test-taker is asked a question of known difficulty. If the question is answered correctly, a more difficult question is asked. Conversely, if the question is answered incorrectly, an easier question is asked. Each question is, then, a function of the **previous** one. Quite

quickly, an asymptote of performance is established. If the performance of an examination candidate is marginal, the computer can dwell on the subject until it is certain that the measure is reliably above or below the pass-fail line. If performance is more than adequate, it can move on the another subject. Alternatively, adaptive testing can be used prescriptively to **profile** a learner's knowledge and provide references for remedial reading. One can imagine a scenario in which a student beginning a clerkship is handed a CD-ROM disk. The program questions the student to assess his level of information. It then prescribes a program of study composed of references contained on the same disk. At the conclusion of the clerkship it again examines the student to determine knowledge gained. While this scenario borders on fantasy in mid-1988, current technology should make it feasible in time.

CONCLUSION

Physicians are essentially information processors. **Computers** have the capacity to **simulate** the physician's problem-solving process. Constructed wisely, **computer** programs can reduce the time necessary to achieve a given level of mastery of subject material. Used effectively, they can alter physician and student behavior to the benefit of **patient** care. **Computers** can, as well, do something that physicians cannot do. They can memorize (store) huge amounts of information that may then be made available to the physician when and as it is needed.

The challenge to educators is to develop the potential that computers provide. The effort will require commitment of resources and cooperation among institutions. The outcome, however, is a promise for a more efficient educational process and improved **patient** care.

From the Office of Continuing **Medical** Education, George Washington University **Medical** Center, Washington, DC.

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This is the third in a series of Special Communications organized by the Symposium on Computer Applications in **Medical** Care, Inc. [n42,n43]

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USPT	l9 and ((health with state) or contidion)		108	L10
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